CPE 323 Introduction to Embedded Computer Systems: Introduction

Instructor: Dr Aleksandar Milenkovic
CPE 323

- Syllabus
  - textbook & other references
  - grading policy
  - important dates
  - course outline

- Prerequisites
  - Number representation
  - Digital design: combinational and sequential logic
  - Computer systems: organization

- Embedded Systems Laboratory
  - Located in EB 106
  - EB 106 Policies
  - Introduction sessions
  - Lab instructor
CPE 323

- LAB Session
  - on-line LAB manuals and tutorials
  - Access cards
  - Accounts

- Lab Assistant: Zahra Atashi

- Lab sessions
  - #1 – Monday 10:00 – 11:30 AM
  - #2 – Wednesday 7:00 – 8:30 PM

- Backup
  - Wednesday 10:00 – 11:30 AM
  - Monday 7:00 – 8:30 PM

- Sign-up sheet
Outline

- Computer Engineering: Past, Present, Future
- Embedded systems
  - What are they?
  - Where do we find them?
  - Structure and Organization
  - Software Architectures
What Is Computer Engineering?

- The creative application of engineering principles and methods to the design and development of hardware and software systems.
- Discipline that combines elements of both electrical engineering and computer science.
- Computer engineers are electrical engineers that have additional training in the areas of software design and hardware-software integration.
What Do Computer Engineers Do?

- Computer engineers are involved in all aspects of computing
- Design of computing devices (both Hardware and Software)
- Where are computing devices?
  - Embedded computer systems (low-end – high-end)
    - In: cars, aircrafts, home appliances, missiles, medical devices,…
    - Entering: clothes, shoes, pens, … everything will go smart
  - Mobile personal communicators/digital assistants
  - Game consoles
  - Personal computers
  - High-end servers
  - Clusters, supercomputers
History of Computing

Ongoing: laptop => handheld

1 billion phones in 2007 => one for every human

Log price

Mainframe

Mini

WS

PC

Notebook

Handheld

Ubiquitous

Time
Intel: First 30+ Years

Intel 4004
- November 15, 1971
- 4-bit ALU, 108 KHz, 2,300 transistors, 10-micron technology

Intel Pentium 4
- August 27, 2001
- 32-bit architecture, 1.4 GHz (now 3.08), 42M transistors (now 55+M), 0.18-micron technology (now 0.09)
## Technology Directions: SIA Roadmap

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Feature size (nm)</td>
<td>180</td>
<td>130</td>
<td>100</td>
<td>70</td>
<td>50</td>
<td>35</td>
</tr>
<tr>
<td>Logic trans/cm²</td>
<td>6.2M</td>
<td>18M</td>
<td>39M</td>
<td>84M</td>
<td>180M</td>
<td>390M</td>
</tr>
<tr>
<td>Cost/trans (mc)</td>
<td>1.735</td>
<td>.580</td>
<td>.255</td>
<td>.110</td>
<td>.049</td>
<td>.022</td>
</tr>
<tr>
<td>#pads/chip</td>
<td>1867</td>
<td>2553</td>
<td>3492</td>
<td>4776</td>
<td>6532</td>
<td>8935</td>
</tr>
<tr>
<td>Clock (MHz)</td>
<td>1250</td>
<td>2100</td>
<td>3500</td>
<td>6000</td>
<td>10000</td>
<td>16900</td>
</tr>
<tr>
<td>Chip size (mm²)</td>
<td>340</td>
<td>430</td>
<td>520</td>
<td>620</td>
<td>750</td>
<td>900</td>
</tr>
<tr>
<td>Wiring levels</td>
<td>6-7</td>
<td>7</td>
<td>7-8</td>
<td>8-9</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>Power supply (V)</td>
<td>1.8</td>
<td>1.5</td>
<td>1.2</td>
<td>0.9</td>
<td>0.6</td>
<td>0.5</td>
</tr>
<tr>
<td>High-perf pow (W)</td>
<td>90</td>
<td>130</td>
<td>160</td>
<td>170</td>
<td>175</td>
<td>183</td>
</tr>
</tbody>
</table>
# Performance Trends

<table>
<thead>
<tr>
<th>Year</th>
<th>Proc.</th>
<th>MIPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1969</td>
<td>4004</td>
<td>0.06</td>
</tr>
<tr>
<td>1970’s</td>
<td>808x</td>
<td>0.64</td>
</tr>
<tr>
<td>1982</td>
<td>286</td>
<td>1</td>
</tr>
<tr>
<td>1985</td>
<td>386</td>
<td>5</td>
</tr>
<tr>
<td>1989</td>
<td>486</td>
<td>20</td>
</tr>
<tr>
<td>1993</td>
<td>Pentium</td>
<td>100</td>
</tr>
<tr>
<td>1996</td>
<td>P II</td>
<td>250</td>
</tr>
<tr>
<td>1999</td>
<td>P III</td>
<td>500</td>
</tr>
<tr>
<td>2000</td>
<td>P 4</td>
<td>1500</td>
</tr>
</tbody>
</table>
Clock Frequency Growth Rate

- 30% per year

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Transistor Count Growth Rate

Moore’s Law
Storage

- Divergence between memory capacity and speed more pronounced
  - Capacity increased by 1000x from 1980-95, speed only 2x
  - Gigabit DRAM by c. 2000, but gap with processor speed much greater

- Larger memories are slower, while processors get faster
  - Need to transfer more data in parallel
  - Need deeper cache hierarchies
  - How to organize caches?

<table>
<thead>
<tr>
<th></th>
<th>Speed</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Registers</td>
<td>ns</td>
<td>~KB</td>
</tr>
<tr>
<td>Cache</td>
<td>10ns</td>
<td>~MB</td>
</tr>
<tr>
<td>Main memory</td>
<td>100ns</td>
<td>~100MB</td>
</tr>
<tr>
<td>Hard disk</td>
<td>10ms</td>
<td>~10GB</td>
</tr>
<tr>
<td>Archive</td>
<td>&gt;100ms</td>
<td>~TB</td>
</tr>
</tbody>
</table>
General Technology Trends

- Microprocessor performance increases 50%-100% per year
- Transistor count doubles every 3 years
- DRAM size quadruples every 3 years
- Huge investment per generation is carried by huge commodity market
Trends & Challenges

- Processor/memory discrepancy
  - Memory hierarchy
  - On-chip/off-chip memory

- Microprocessor execution
  - Fetch > Decode > Execute

- System on a chip - Microcontroller
  - Cost, smaller PCB, reliability, power.
  - Applications

- Evolution
  - Microprocessor
  - Microprocessor-on-a-chip
  - System-on-a-chip
  - Distributed-system-on-a-chip
More on Challenges

- Scalability
  - billions of small devices
  - performance

- Availability
  - hardware changes
  - system upgrade
  - failures
  - code enhancements

- Fault tolerance
Outline

- Computer Engineering: Past, Present, Future
- Embedded systems
  - What are they?
  - History of embedded systems
  - Where do we find them?
  - Structure and Organization
  - Software Architectures
What are Embedded Computer Systems

- An embedded system is a special-purpose computer system designed to perform one or a few dedicated functions.

Main Characteristics

- Usually embedded as a part of a complete device that serves a more general purpose (e.g., in car or in MP3 player).
- Usually heavily optimized for the specific tasks, reducing cost of the product or reducing the size or increasing the reliability and performance.
- Often with real-time computing constraints that must be met, for reasons such as safety (e.g., anti-block systems) and usability (e.g., video consoles).
- Range from low-end 4-bit microcontrollers to high-performance multiple processor cores on a single chip.
- Software written for embedded systems is often called firmware, and is usually stored in read-only memory or Flash memory chips rather than a disk drive.
Early History of Embedded Systems

- Apollo Guidance Computer
  - One of the first publicly recognized embedded systems
  - Developed by Charles Stark Draper at the MIT Instrumentation Laboratory
- Autonetics D-17 (1961)
  - Guidance computer for the Minuteman missile
- Intel 4004 (1971), first microprocessor
  - Used in calculators
- Automobiles used microprocessor-based engine controllers (1970’s)
  - Control fuel/air mixture, engine timing, etc.
  - Multiple modes of operation: warm-up, cruise, hill climbing, etc.
  - Provides lower emissions, better fuel efficiency
Modern Embedded Systems

- Modern Microcontrollers: (mid 1980s)
  - Microprocessors that include I/O devices and on-chip memory on a chip
- Digital Signal Processors (DSP):
  - Microprocessors optimized for digital signal processing
- Typical embedded processor word sizes: 8-bit, 16-bit, 32-bit
Embedded Systems Applications

- Telecommunication equipment: telephone switches, voice and data network bridges and routers
- Consumer electronics: MP3 players, DVD players, digital cameras, GPS receivers, game consoles, …
- Home appliances: microwave ovens, dishwashers, washers, …
- Transportation systems: aviation electronics (avionics), vehicle electronics (to increase efficiency and safety, reduce pollution, …)
- Medical electronics: health monitors, medical imaging (PET, SPECT, CT, MRI)
Future Applications

- Deeply embedded into the environment
  - Wireless Sensor Networks

- Applications
  - Health Monitoring
  - Smart Transportation Systems
  - Smart Roads
  - Habitat Monitoring
  - Military
  - …

- Wireless Sensor Networks @ UAHuntsville
  - TinyHMS and SVEDECs
TinyHMS for Ubiquitous Health Monitoring

ECG & Tilt sensor
SpO2 & Motion sensor
Body Area Network
Motion sensors

Personal Server
Network coordinator & temperature/humidity sensor

ZigBee

GPRS
Bluetooth or WLAN

Internet

Weather Forecast
Emergency
Caregiver
Medical Server
Physician
TinyHMS: Hardware
TinyHMS: Software

Motion Sensor (TS2)

ECG Sensor (TS1)

Heart Beat

Beacon Message

Event Message with Timestamp

Frame i-1

Frame i

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SVEDECs

Traffic Monitoring Using TMotes

Vehicle Detection (speed, size)
Embedded Systems Organization

- 4 major components: CPU, Memory, System Bus, and I/O Peripherals
CPUs

Unlike the personal and server computer markets the embedded processors are fairly diverse featuring

- Von Neumann as well as Harvard architectures
- RISC as well as non-RISC and VLIW;
- Word lengths from 4-bit to 64-bits and beyond (mainly in DSP processors) although the most typical remain 8/16-bit.
- A large number of different variants and shapes, many of which are also manufactured by several different companies
- Common architectures are: 65816, 65C02, 68HC08, 68HC11, 68k, 8051, ARM, AVR, AVR32, Blackfin, C167, Coldfire, COP8, eZ8, eZ80, FR-V, H8, HT48, M16C, M32C, MIPS, MSP430, PIC, PowerPC, R8C, SHARC, ST6, SuperH, TLCS-47, TLCS-870, TLCS-900, Tricore, V850, x86, XE8000, Z80, etc.

- Typically embedded CPUs are integrated together with memories and I/O peripherals on a single chip to reduce the cost and size and increase reliability
I/O Peripherals

- Embedded Systems talk with the outside world via peripherals, such as:
  - Serial Communication Interfaces (SCI): RS-232, RS-422, RS-485 etc
  - Synchronous Serial Communication Interface: I2C, JTAG, SPI, SSC and ESSI
  - Universal Serial Bus (USB)
  - Networks: Ethernet, Controller Area Network, LonWorks, etc
  - Timers: PLL(s), Capture/Compare and Time Processing Units
  - Discrete IO: aka General Purpose Input/Output (GPIO)
  - Analog to Digital/Digital to Analog (ADC/DAC)
A Microcontroller-Based System: An Example

- LCD
- RS232
- RS232 controller
- Analog I/O
- 2-axes joystick
- LEDs
- Switches
- Thermistor
- Keypad
- μC: MSP430
Data Flow

$t, \text{ states}$

A/D Input

μP system Processing

D/A Output

Temperature sensor

control signals

INPUT PROCESSING OUTPUT

μP

78°
Backup Slides
Von Neumann Architecture

- Processing Elements
  - sequential execution
- Read/Write Memory
  - linear array of fixed size cells
  - Data and instruction store
- I/O unit
- Address/Data/Control bus
Von Neumann Architecture

Memory

W bits

0
1
2
3
N
\log_2 N

PE (Processing Element)

Control Unit

ALU

Read/Write Memory

address

control

data

I/O (peripherals)
Von Neumann vs. Harvard

Von Neumann Architecture

Read/Write Memory

PE

(Processing Element)

address

data

Harvard Architecture

Program Memory

Data Memory

PE

(Processing Element)

Program Memory

Data Memory

address

data

address

data